The 0□2□-decay Experiments

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(1) Motivations:

- Neutrino's Nature
- Neutrino's Mass

(2) Experiments

I. Bandac, C. Bucci, S. Freeman, P. Gorla, T. Gutierrez, J. Thomas, F. Vassani

1930 - W. Pauli and □

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Public letter to the group of the Radioactives at the district society meeting in Tübingen:
Physikalisches Institut
der Eidg. Technischen Hochschule
Gloriastr.
Zürich

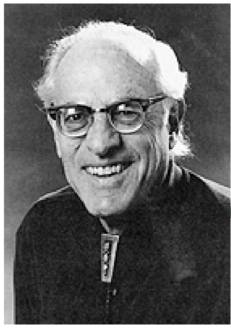
Zürich, 4 December 1930

“As the bearer of these lines, to whom I graciously ask to listen, will explain to you in more detail, how because of the ‘wrong’ statistics of the N and ^{6}Li nuclei and the continuous beta-spectrum. I have hit upon a desperate remedy to save the ‘exchange theorem’ of statistics and the law of conservation of energy. ***Namely, the possibility that there could exist in the nuclei electrically neutral particles, that I wish to call neutrons, which have the spin 1/2 and obey the exclusion principle and which further differ from light quanta in that they do not travel with the velocity of light. The mass of the neutrons should be of the same order of magnitude as the electron mass and in any event not larger that 0.01 proton masses.*** – The continuous beta-spectrum would then become understandable by the assumption that in beta-decay, a neutron is emitted in addition to the electron such that the sum of the energies of the neutron and electron is constant.

….

I admit that on a first look my way out might seem to be quite unlikely, since one would certainly have seen the neutrons by now if they existed. But nothing ventured nothing gained, and the seriousness of the matter with the continuous beta-spectrum is illustrated by a quotation of my honored predecessor in office. Mr. Debye, who recently told me in Brussels: ‘Oh, it is best not to think about it, like the new taxes.’ Therefore one should earnestly discuss each way of salvation. – So, dear Radioactives, examine and judge it. – Unfortunately I cannot appear in Tübingen personally, since I am indispensable here in Zurich because of a ball on the night of 6/7 December. – With my best regards to you, and also Mr. Back, your humble servant.”

W. Pauli



1956, $\bar{\nu}_e$ was discovered

Twenty six years later, in 1956, Reines and Cowan first observed the electron anti-ν.

Today, after seventy five years of Pauli's prediction, fundamental properties of neutrino remain to be mysteries:
- neutrino and its anti-particle
- neutrino mass
- in SM, the knowledge of our understand of the Nature, $m_\nu = 0$

Consequences:
- Inside: the structure and symmetry of elementary particles
- Outside: the beginning and evolution of our universe

ν-Oscillation

$$\nu_{f,L} = \sum_{i=1}^{3} U_{f,i}\,\nu_{i,L}$$

L : *left handed*

f : *flavor eigenstate*

i : *mass eigenstate*

$U_{f,i}$: *PMNS neutrino mixing matrix*

1) Including Dirac and Majorana CP violation phases
2) PMNS mixing matrix: neutrinos have mass, oscillations

B. Pontecorvo, Zh. Eksp., Teor. Fiz. ***33**, 54(57);* ***34**, 247(58)*
Z. Maki, M. Nakagawa, and S. Sakata, Prog. Theor. Phys., ***28**, 870 (62)*

ν-Oscillation Results

1) Solar: Homestake, Kamiokande, SAGE GALLEX/GNO, SK, SNO
2) Atmospheric: SK, SNO
3) Reactor: KamLAND

$$\Delta m^2_{1,2} = (7.2 \pm 0.7) \times 10^{-5}\, eV^2 \qquad \Delta m^2_{i,j} = m^2_j - m^2_i$$

$$\left|\Delta m^2_{2,3}\right| = (2.0 \pm 0.4) \times 10^{-3}\, eV^2$$

$$\tan^2 \theta_{1,2} = 0.44 \pm 0.05$$

$$\sin^2 2\theta_{2,3} = 1.00 \pm 0.04$$

$$\sin^2 2\theta_{1,3} = 0.000 \pm 0.085$$

*F. Feruglio, A. Strumia, and F. Vissani, Nucl. Phys. **B637**, 345(02); **B659**, 359(03)*

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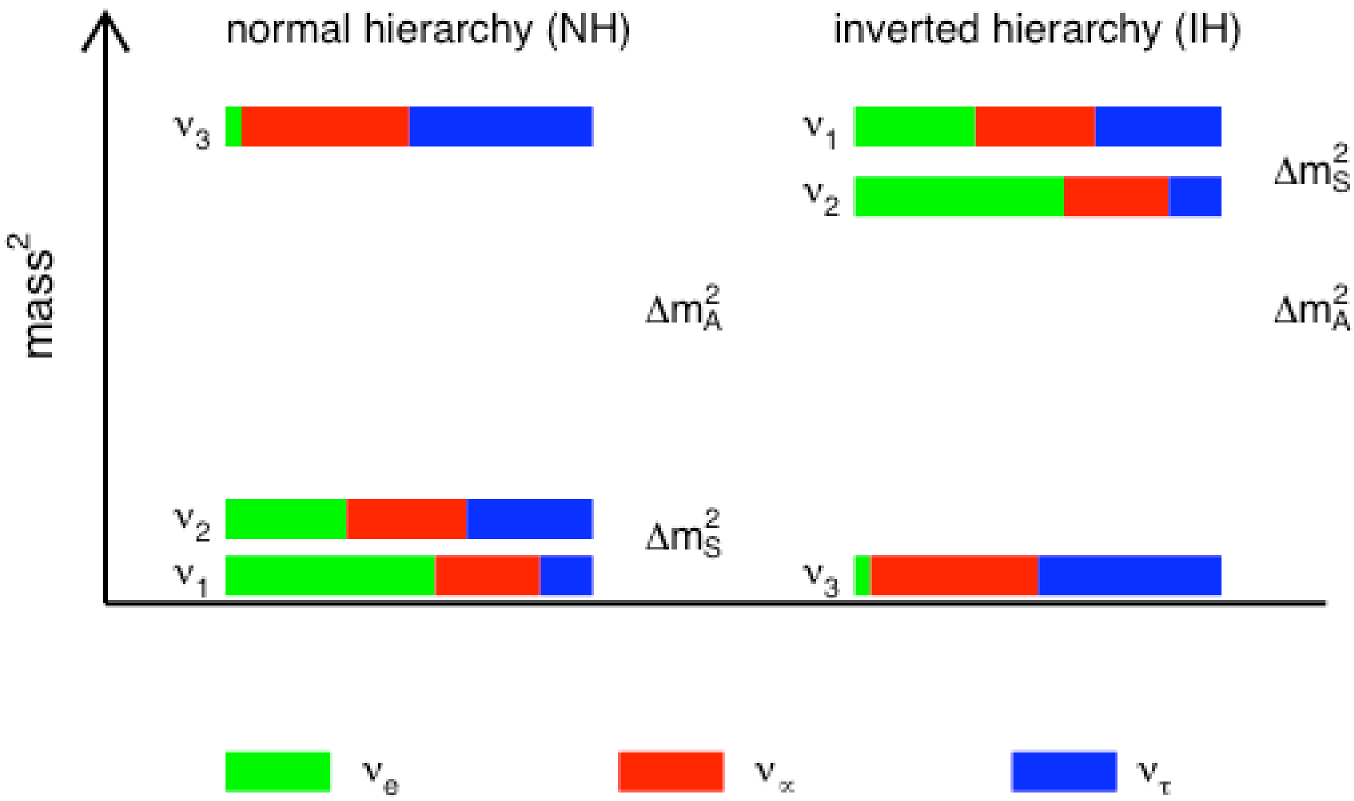
ν-Oscillation Results (cont.)



Neutrino's nature ?

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In oscillation experiment, only the mass^2 differences are determined which means neutrinos have finite mass. We need to know the nature of neutrino and their masses.

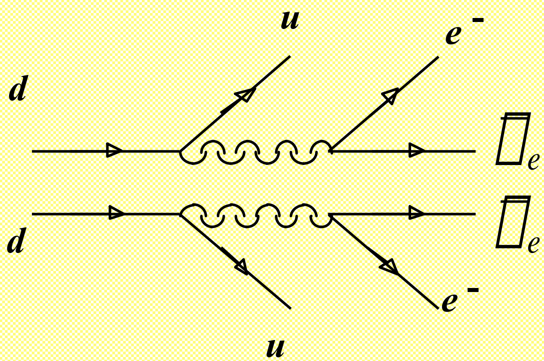
$$\nu_i \neq \bar{\nu}_i$$

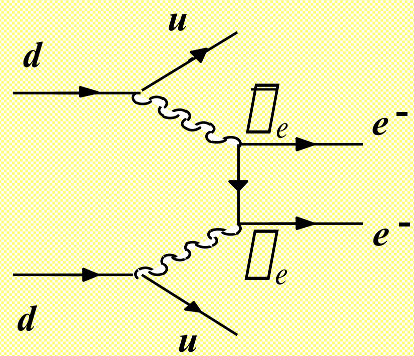
Dirac type

$$\nu_i = \bar{\nu}_i$$

Majorana type
Lepton # conservation violated
Beyond SM

Double beta-decay





$$\nu_f \neq \bar{\nu}_f$$

Dirac type

2ν2β decay

$$\nu_f = \bar{\nu}_f$$

Majorana type

0ν2β decay

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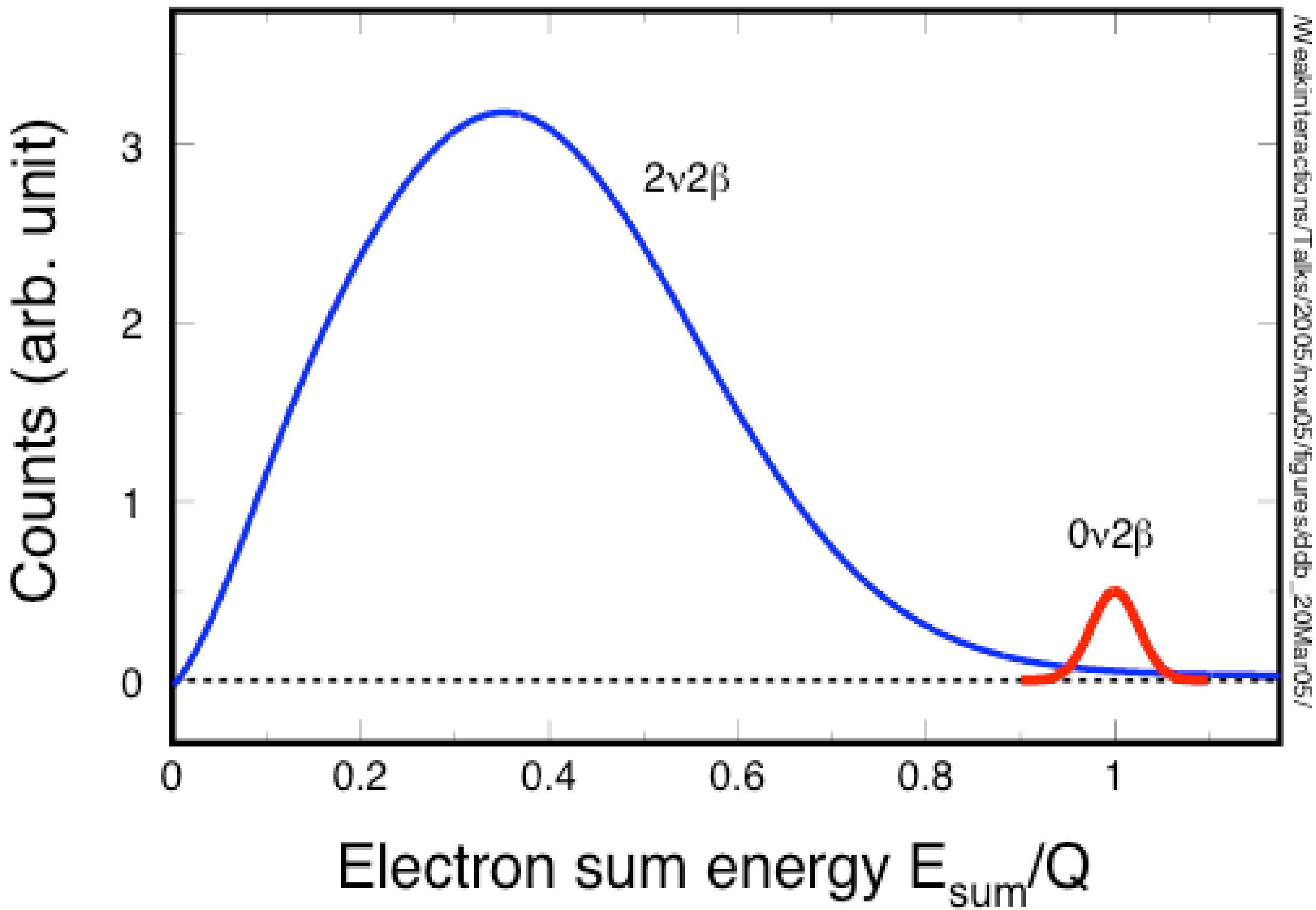
Double beta-decay (cont.)



Experiment Methods

Fermi's golden rule

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Measurements

Phase space integral

Neutrino mass

$$\left[T_{1/2}^{0\nu}\right]^{-1} = G^{0\nu} \times \left|M^{0\nu}\right|^{2} \times \langle m_{\nu} \rangle^{2}$$

Nuclear decay matrix elements
Large model uncertainties

Present Limits

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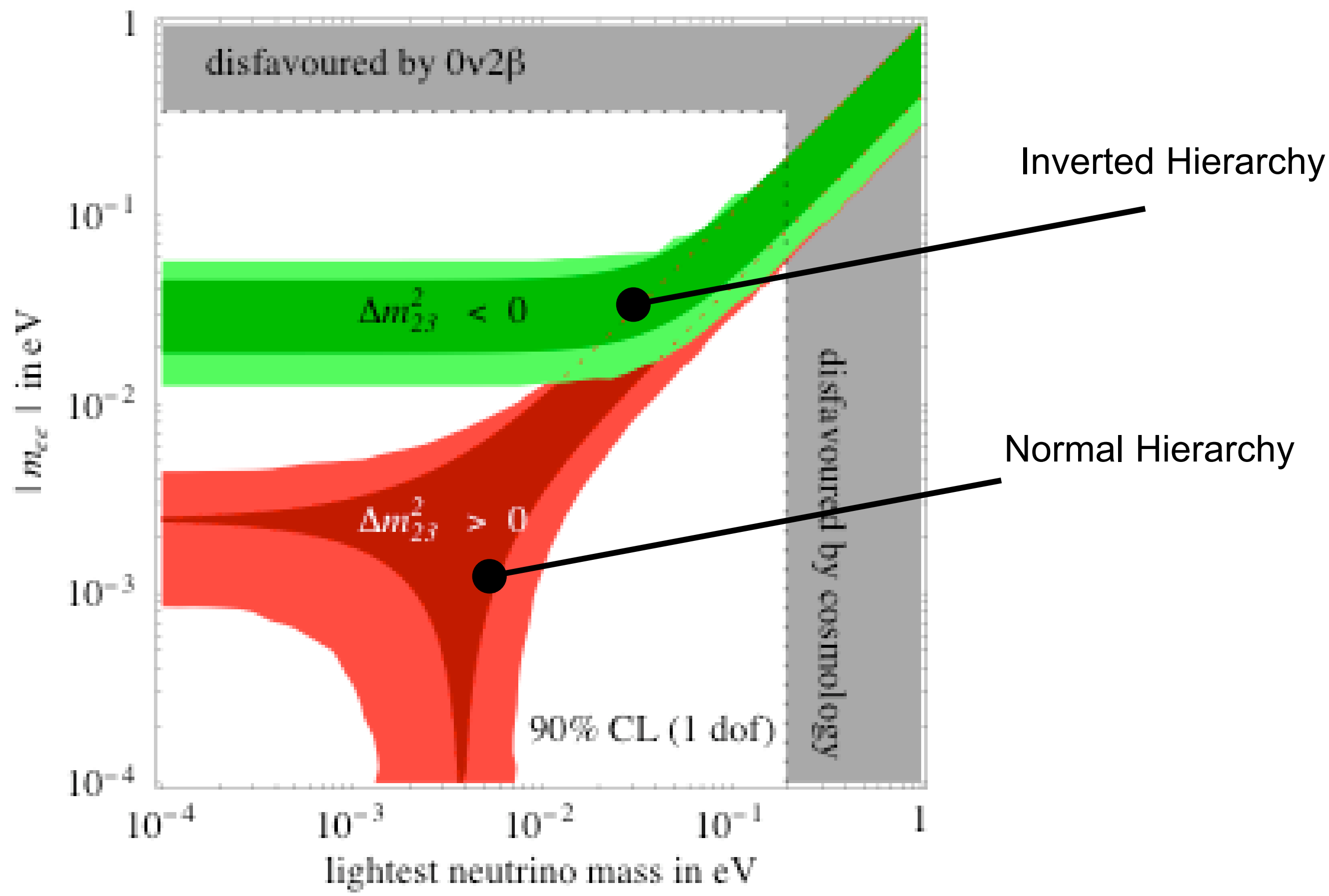

F. Feruglio, A. Strumia, and F. Vissani, Nucl. Phys. ***B637****, 345(02);* ***B659****, 359(03)*

CUORE/CUORICINO

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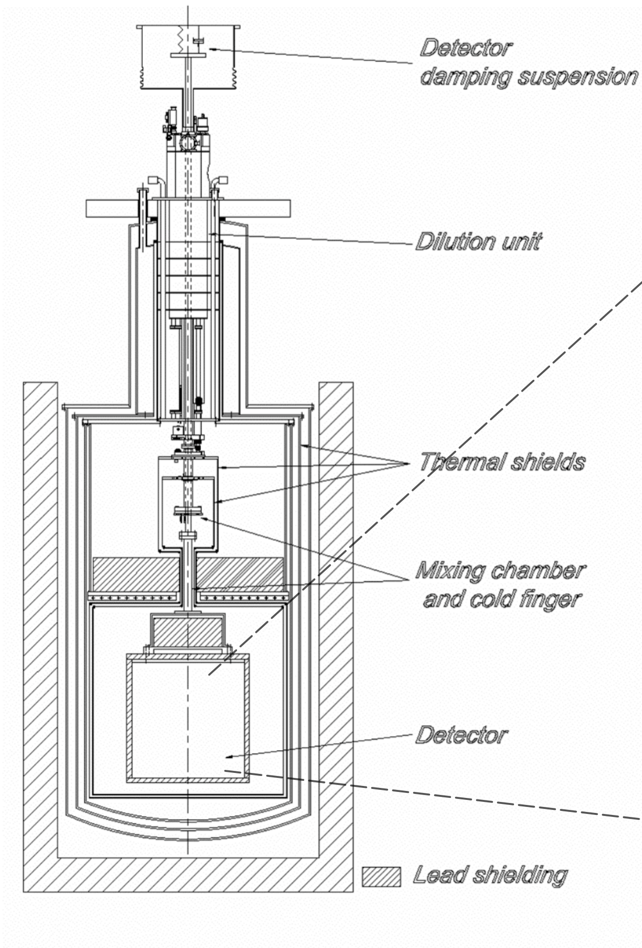
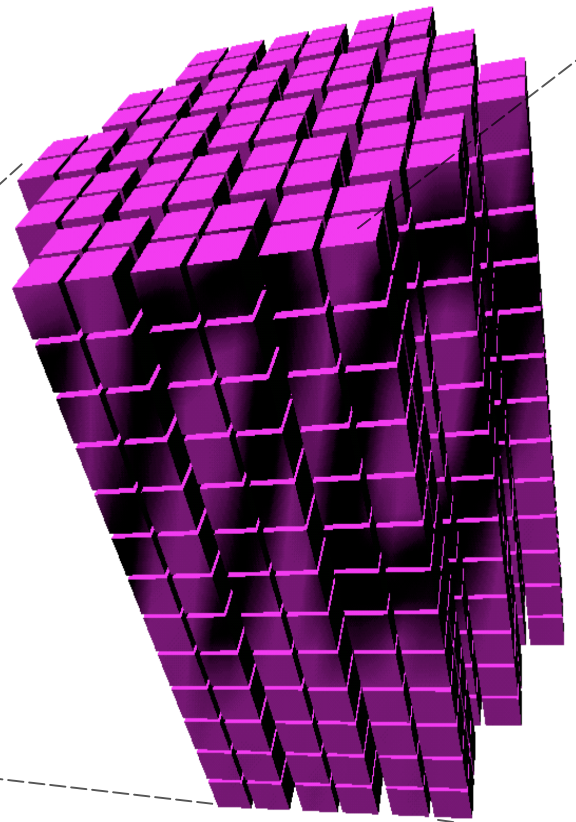
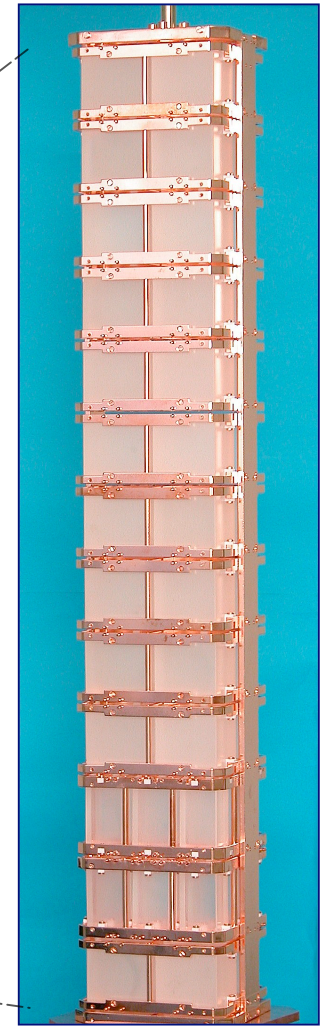
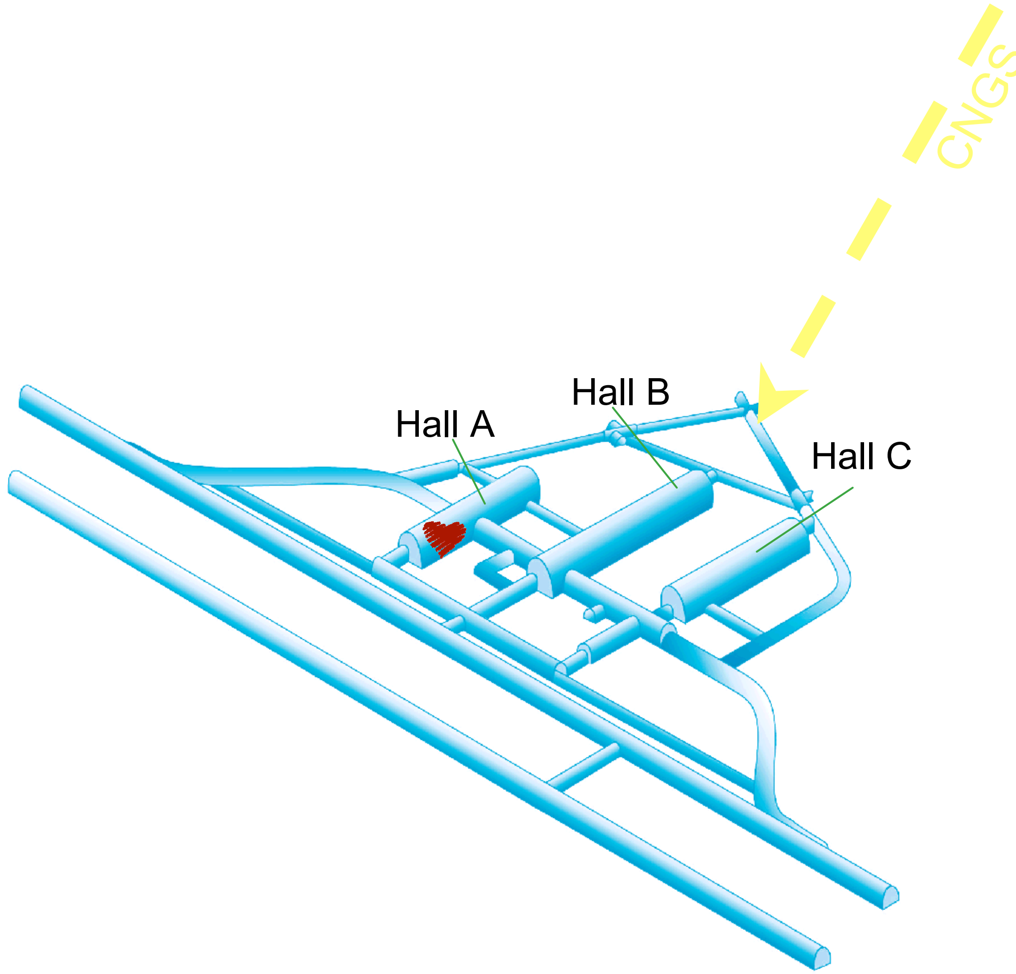
http://crio.mib.infn.it/wig/Cuorepage/CUORE.php







Laboratori Nazionali Del Gran Sasso (LNGS)



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MAJORANA

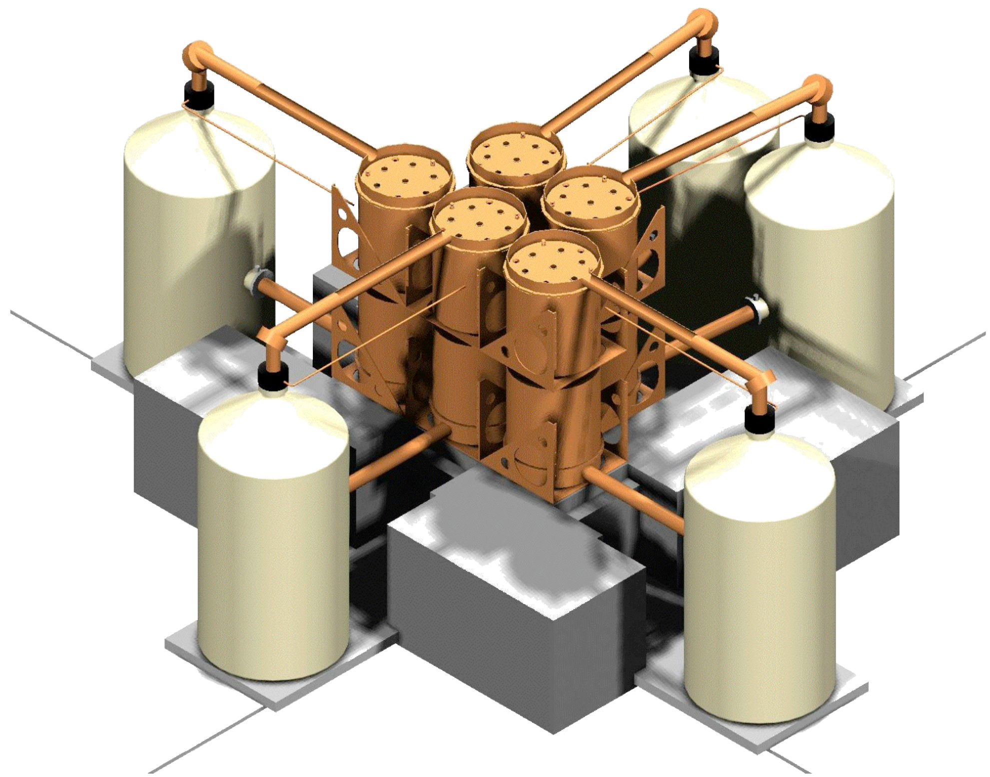
1) US underground laboratory

2) Enriched ^{76}Ge, 500kg

3) $T_{1/2} \geq 10^{27}$

   $\langle m_{\nu} \rangle \leq 0.02 - 0.07$ eV

White paper: *nucl-ex/0311013*



Next Generation 0ν2β Experiments

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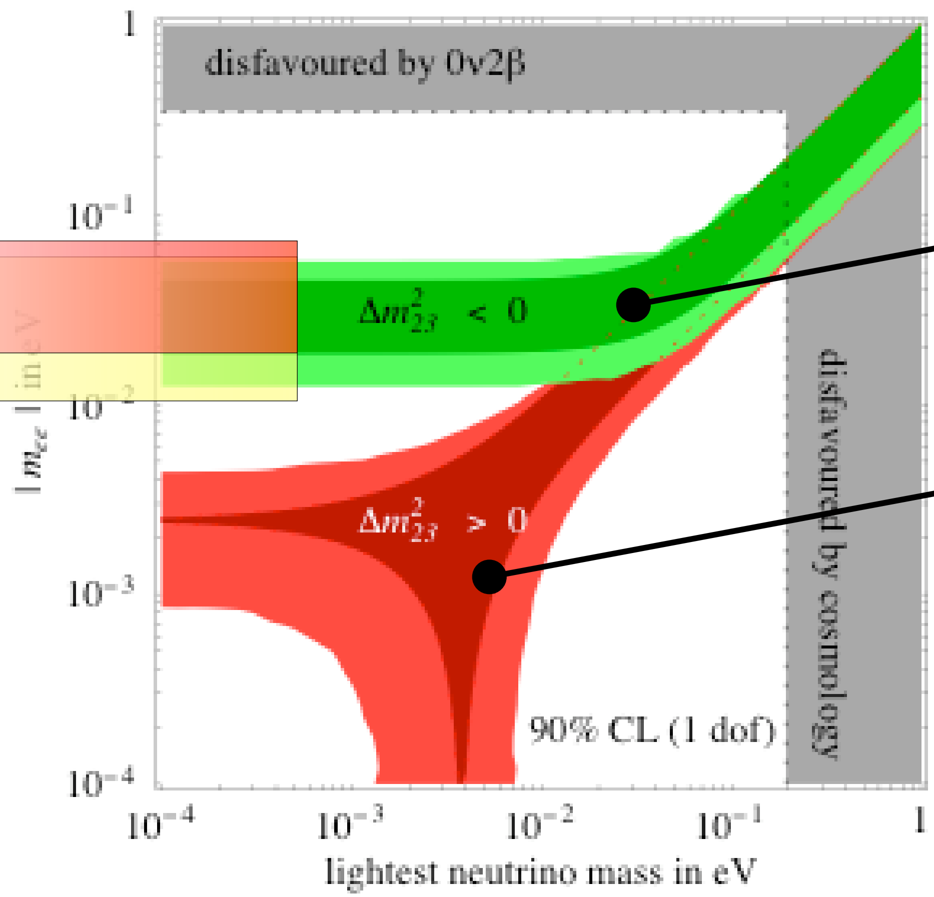
CUORE $^{130}Te^{nat}$

Majorana $^{76}Ge^{enr}$



Inverted Hierarchy

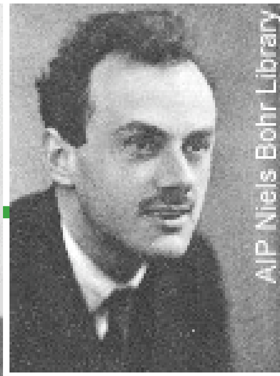
Normal Hierarchy

F. Feruglio, A. Strumia, and F. Vissani, Nucl. Phys. ***B637****, 345(02);* ***B659****, 359(03)*

Summary

Next generation $0\nu2\beta$ experiments potentials:

- Rule out inverted hierarchy scenario, based on today's model limit.
- Discover neutrino nature.
- Determine neutrino mass.



References

1) Majorana experiment: *nucl-ex/0311013*

2) CUORE experiment: http://crio.mib.infn.it/wig/Cuorepage/CUORE.php

3) SNO: http://www.sno.phy.queensu.ca/

4) KamLAND: http://www.awa.tohoku.ac.jp/KamLAND/

5) Experiments at LNGS:
http://www.lngs.infn.it/lngs_infn/index.htm?mainRecord=http://www.lngs.infn.it/lngs_infn/contents/lngs_en/research/experiments_scientific_info/

6) "The Neutrino Matrix", physics/0411216.

7) …